National Aeronautics and Space Administration

MEASUREMENT OF WATER ICE DIELECTRIC PROPERTIES NEEDED FOR RADAR SOUNDER OBSERVATIONS

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Project Objective:

The objective of this task was to design and construct a specialized laboratory instrument for accurately measuring the complex dielectric permittivity of various types of ice at temperatures as low as 150 K, and over the frequency range of 0.1 MHz to 100 MHz.

This instrument will be used by the JPL Planetary Ices Laboratory and our Caltech collaborators to study the dielectric properties of planetary ice/soil analogs and provide published data of vital interest to the scientific community for present and future mission support.

FY09 Results:

To cover the entire range with good accuracy using only one instrument and meet the other design goals required extensive effort in RF and mechanical design, modeling and simulation. The results of this effort are shown in Figures 1 and 2. This construction has several advantages over conventional designs: it provides superior RF performance; it maintains tight tolerances and high reliability over many thermal cycles; and it allows the electrodes to be easily removed and replaced. Once removed, the electrode can be mounted on a microtome to allow the sample to be accurately planed parallel *in situ*. Furthermore, because the electrodes are used with a bridge circuit that places all adjacent conductors at the same electric potential, the large ground plane ensures that fringing field effects will be small, even with thick samples. To simultaneously achieve the many design goals, finite element modeling (FEM) and simulation were important in the design process (Fig. 3).

An important aspect of this instrument is that it allows the testing of the same sample over a wide range of temperatures because the sample holder adapts to the geometry of the sample as it responds to thermal variations. This limits the risk of using samples with slightly different microstructure and chemical properties when investigating the dielectric properties of a given icy composition.

Benefits to NASA and JPL (or significance of results):

Ground penetrating radar (GPR) has become an important tool for determining the structure and composition of planetary bodies. Several ongoing or upcoming missions include a GPR acting in the 1 to 100 MPa frequency range, e.g., Airbone observations at Antarctica and Greenland, SHAllow RADar instrument on the Mars Reconnaissance Orbiter, Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on the Mars Express mission, CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) instrument on the Rosetta spacecraft, and future GPR in the Europa and Jupiter System Mission.

For the radar measurements to be properly interpreted, it is necessary to understand and measure the dielectric properties of materials from which the body is known or believed to be formed. In the case of future GPR observations at outer Solar system objects, the absence of dielectric measurements obtained on analogs for the low temperatures and exotic ices expected at these objects (e.g., clathrate hydrates, amorphous ice, salt hydrates, ammonia hydrates, etc.) is a limitation to science definition and science planning efforts.

Before that task was undertaken, there was no such instrument capable of working in cryogenic conditions with that level of control on temperature, stress, and sample geometry. Also, most measurements available in the literature have been achieved at temperatures greater than 190 K (the coolant being dry ice). However very few studies have been able to achieve temperatures as low as 150 K, required for the investigation of the dielectric properties of a variety of hydrates, and especially ammonia hydrates.

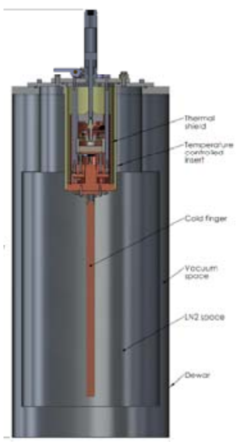

Figure 1. Cutaway view of the complete instrument. The temperature controlled insert remains attached to the dewar during use; its cold finger remains dipped in liquid nitrogen to provide cooling for the instrument. The bottom plate of the insert is equipped with a thermometer and heater to provide a stable base temperature for the cryostat. A copper tube extending upward from the bottom plate surrounds the cryostat assembly and acts as a thermal shield, cooling and stabilizing the air temperature around the electrode assemblies. When the temperature of this shield is set just below the sample temperature, sublimation can be made negligible. The cryostat is removed from the insert for sample loading and unloading. Electrical and plumbing connections are not shown.

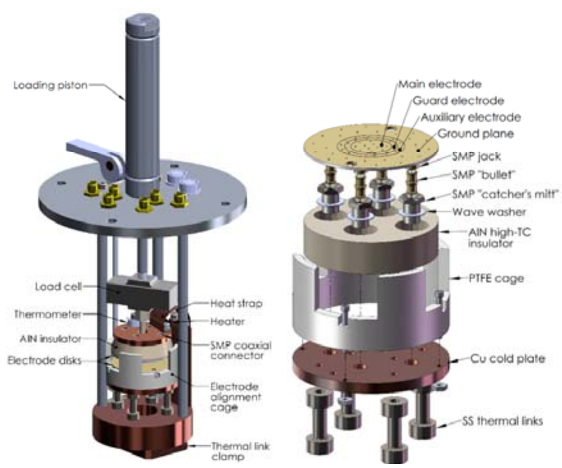

Figure 2. The left figure shows the cryostat assembly. The cryostat makes thermal contact with the cold source at the bottom of the temperature controlled insert using a lever actuated thermal link clamp. A 0.5 in diameter circular cylindrical sample up to 5 mm long is centered between the two electrode disks. Axial sample load is provided by a pneumatic piston which is isolated thermally from the electrodes using a ceramic pivot. The piston withdraws the pivot to allow sample and electrode change. The pivot and an alignment cage made of PTFE constrain the electrodes laterally but allow for variations in electrode separation and tilt to accommodate sample variability. The right figure shows the bottom electrode disassembled. The gold-plated electrodes are removable and fabricated using standard 2-sided PCB techniques on glass-epoxy composite. Numerous plated through holes provide low-impedance electrical and thermal connections to contacts and SMP connectors on the back side. The sample covers the main electrode and part of the guard electrode to prevent sample surface currents from contaminating the measurement. The auxiliary electrode ring has the same surface area as the main electrode allowing the permittivity to be determined directly from the ratio of the two electrode signal amplitudes. Thus, variations in sample thickness due to preparation or temperature do not affect the final measurement. Electrical connections are made using SMP connectors and coaxial cables which are thermally anchored to a temperature controlled plate.

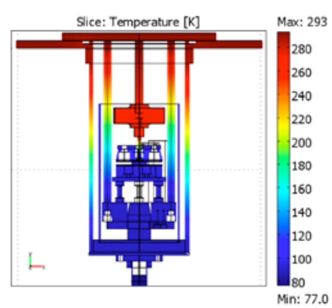

Figure 3. 3-D thermal finite element modeling (FEM) results used for determining component thermal impedances, calculated using Comsol Multiphysics. This model neglects convective and radiative heat transfer. A separate, further simplified, 2D axially symmetric model was used to estimate convective and radiative contributions. These data were used to construct a simplified model of the thermal circuit, complete with temperature controllers, using an electrical circuit analogy. This model could be quickly solved and variations quickly tested, facilitating optimization of the design.

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